

Magnetic Resonance Force Microscope Underlying principles

Force Detection of Magnetic Resonance

Magnetic Resonance Imaging

$\omega_z = \gamma B(x_z)$
 $\omega_x = \gamma B(x_x)$

- Field Gradient, ∇B
→ yields position-dependent resonant frequency, ω
- Resolution \sim $\left(\frac{\text{linewidth}}{\text{field gradient}} \right)$

Atomic Force Microscopy

- Compliant Cantilever
- Optical Displacement Readout
- Sharp Tip
→ its shape determines resolution

INGREDIENTS:

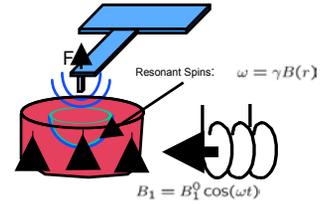
sensitive force detector

- compliant mechanical element
- displacement readout

miniature magnet

generates field gradients:

- provides coupling to spins
- $F = (m \cdot \nabla) B$
- defines magnetic resonance imaging volume
- $\omega(r) = \gamma B(r)$



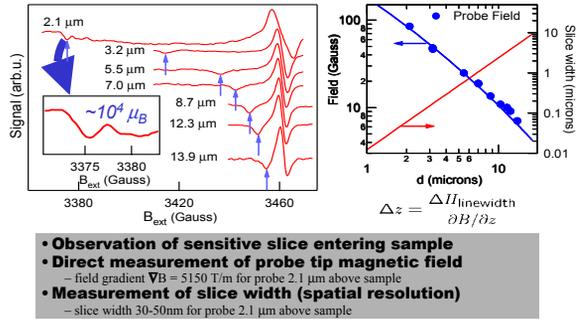
J. A. Sidles, Appl. Phys. Lett. 58, 2854 (1991)

Magnet on Cantilever Scanned MRFM Instrument

Scanned Magnetic Resonance Tool

- Fully scanning microscope
- Scanned magnetic probe (on cantilever)
 - Arbitrary samples
- Low temperature
 - High sensitivity
 - T-dependent physics
- Atomic Force Microscope
 - Topographic information

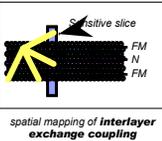
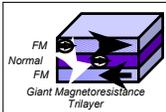
High Sensitivity Electron Spin Resonance



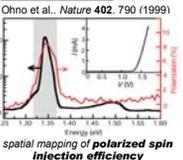
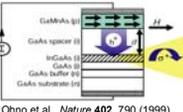
Magnetic Resonance Studies Buried Magnetic Interfaces

NMRFM Mode of Operation: Co Thin Film (Dots)

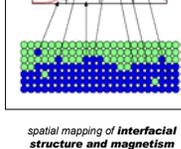
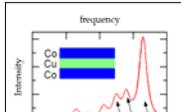
Ferromagnetic Resonance



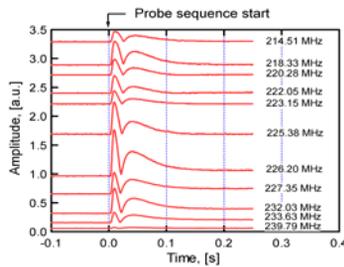
Electron Spin Resonance



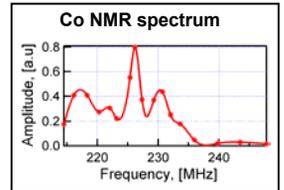
Nuclear Magnetic Resonance



Time dependence of the cantilever vibration amplitude



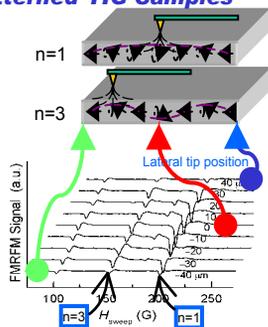
Conditions of signal acquisition:
T = 4 K, $B_{appl} = 0.5$ T, \perp film plane
Probe-sample distance 1 μm



Summary

Caltech FMR Imaging Lateral Scanning in Patterned YIG Samples

- Lateral scan: local detection of magnetization associated with various magnetostatic modes
- Suppression of all modes toward edge of sample
- Non-monotonic dependence of n=3 mode



M. Midzor, P. Wigen, M.L. Roukes D. Pelekhov and P.C. Hammel

New Capabilities

- non-destructive 3D sub-surface imaging
- general magnetic resonance instrument
- imaging with chemical specificity
- ultimate spatial resolution: atomic
- ultimate sensitivity: single spin